

A CLUSTER HEAD ASSISTED ROUTING (CHAR) SCHEME FOR IMPROVED ENERGY LOAD BALANCING IN WIRELESS SENSOR NETWORKS

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ABSTRACT

This study presents a Cluster Head Assisted Routing (CHAR) scheme aimed at reducing the burden on Cluster Heads (CHs) while maintaining the hierarchical structure and its advantages. The Assisting Cluster Head (ACH) collates data within the cluster while the cluster head (CH) is left with the task of transmitting collated data towards the base station (BS). In this manner, the huge energy burden hitherto on the CH is reduced. An energy cost function is developed; which considers the residual energy of the nodes and the energy burden imposed on the cluster should any member is elected as a head. The node that best satisfies the two criteria is favored to be elected as the head. Simulations were carried out in MATLAB and in a test bed using ESP8266, conditioned with power supply unit, a voltage measuring circuit and a firmware, as the wireless sensor nodes. The results revealed an improvement in the energy consumption profile of the CHAR over non cluster head assisted routing. The CHAR scheme recorded a 12.9% improvement in round-count before First Node Death (FND). Other parameters compared are Last Node Death (LND), Residual energy per round and energy left unused at the end of the experiment

KEYWORDS: *Wireless Sensor Network; Routing Protocols; Algorithms; and Power management*

1.0 INTRODUCTION

Wireless Sensor Networks (WSNs) have received a great deal of attention owing to their wide range of applications, and the great potentials minimize cost and improve efficiency of communication systems. They find useful applications in Security (surveillance, detection of IEDs) (Salman-ul-Hassan, Zoya, Fatima, & Umer, 2012), traffic management (monitor the flow of traffic and best route detection in real time) (Munienge, Ekabua, & Isong, 2015), biomedical applications (body sensor network) (Sing-Hui, Kyeong-Hoon, Wan-Young, & Seung-Chul, 2009), industrial control and automation (Kay, Win, & Meng, 2005), and in study-data capturing in environments that maybe hazardous or sometimes inaccessible by humans (Lohith, & Bharatesh, 2015; Sasi, Sushmita, & Amuya, 2013). Although WSNs have been variously applied, the potential of this technology is still limited by a number of design constraints. Some of the important and widely studied issues with WSNs as highlighted by Himani (2014), namely security, hardware design, energy and power management challenges. The security of a WSN, as with any other networks, influences its operability and is also one of the crucial factors that determines whether a network is available or not. According to Lohith & Bharatesh (2015), security issues in WSNs involved data authentication, data confidentiality, and data integrity and data freshness.

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The life and operations of a wireless sensor node are solely dependent on availability of power (typically batteries). Subject to the peculiarities of application, the required life span may be a few hours or may extend to several years (Kay & Friedmann, 2004). Since these batteries are typically limited in size and capacity, and in many applications, infeasible to replace, it is essential to minimize, if not eliminate, all forms of energy wastages and ensure optimal utilization of this limited supply. To this extent, several studies in WSN have converged on the fact that, most of the energy of a sensor node is consumed during transmission (Kay & Friedmann, 2004; Kingsly & Chandra, 2013). It has been revealed by Akyildiz & Vuran (2010) that the energy cost of transmitting a 1 kb packet over a distance of 100 m is approximately equal to executing about 3 million instructions by a typical microprocessor. It is on this premise that it becomes crucial to develop and optimize algorithms that will minimize energy consumed during the communication stage in a WSN (Heinzelman, Chandrakasan, & Balakrishnan, 2002).

Several studies have suggested different approaches of minimizing the energy consumption of WSNs; one of such is to adjust the transmission power to the minimum received power level (Alakesh, & Umapathi, 2014). Another is to employ duty cycling, that is, switching of nodes between different modes (active, sleep and idle) of operation (Lohith & Bharatesh, 2015). A well known approach is the design and optimization of routing schemes (Heinzelman et al., 2002) for efficient transmission within and out of the network. To this end, Low Energy Adaptive Clustering Hierarchy (LEACH) protocol (Heinzelman et al., 2002) and its later versions (Xiaoping, Hong & Gang, 2010; Hari, Ramachandran, & Johnson, 2013) are popular for an improved network lifetime and better throughput (Ossama, Marwan, & Srinivasan, 2006). Despite this fit, these protocols place a huge responsibility on the CHs, leading to faster energy depletion of such heads. It is important therefore to reduce the overhead on the CH and ensure a better spread of energy load in the network, since the death of a few nodes can cause a significant topological change (Alakesh, & Umapathi, 2014).

2.0 MATERIALS AND METHODS

This study presents a design and simulation of an optimized hierarchical-routing scheme, which aims to optimize the energy resource of a WSN by ensuring a more even energy consumption profile of sensor nodes. The overhead on the CH is reduced by implementing the role of an Assisting Cluster Head (ACH) and minimizing unnecessary CH reelections. The ACH shares the workload of the CH; it coordinates the cluster and also aggregates data within the cluster leaving the CH the sole responsibility of inter-cluster transmission of aggregated data. Unlike the primary node proposed in Sandra, Jaime, Miguel, & Jose (2011), the choice of an ACH is not based only on proximity to the CH; a decision cost function is formulated to consider both proximity and residual energy in selecting the principal members of a cluster. In addition, an expectedly swifter next hop decision approach is employed; which should minimize the overhead incurred when the network gets larger. An algorithm was developed, modeled and a comparative examination of its performance was carried out in Matlab environment. In a measure to test the validity of the results, the algorithm was deployed in a quasi-real WSN. An ESP8266 Wi-Fi module was conditioned with an external battery and the C code equivalent of the algorithm to form the wireless sensor node.

2.1 Network Model

The network is comprised of one base station (BS) located outside the monitored area. It is assumed that the monitored area is not readily accessible; hence the location of the BS and a fixed energy budget for all the sensor nodes except the BS. The BS has an unlimited energy budget and can handle all data captured within the network. The model assumptions are as follows:

- All sensor nodes apart from the BS begin with the same initial energy and operate on a fixed energy budget.
- All sensor nodes, including the BS are stationary.
- All sensor nodes can take any of the three possible roles i.e. CH, ACH or normal sensing role.
- All sensor nodes are able to communicate effectively with any other node in the network

2.2 Radio Model And Energy Consumption

The first order radio model, shown in Figure 1, was adopted to compute the energy dissipation in the network.

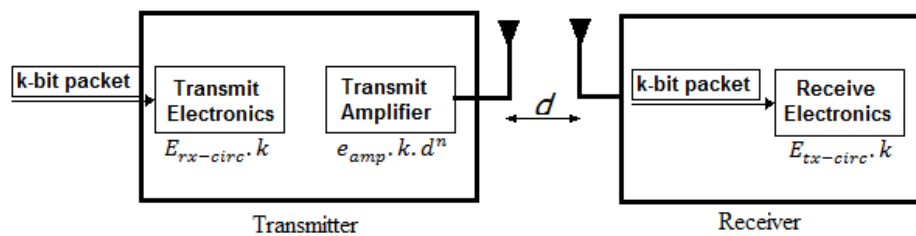


Figure 1. Simplified Energy Model (Kay et al., 2005)

The energy consumption of a transmitter-receiver pair, transmitting a k bit data stream through a distance d can be modeled (Kay et al., 2005) as;

$$E_c = E_{tx}(k, d) + E_{rx}(k) \quad (1)$$

where, E_{tx} and E_{rx} are the energy consumed at the transmitter and receiver respectively. E_{rx} is a function of the receiver circuitry and the packet length received; whereas, E_{tx} can be broken into two parts; energy consumed by the transmitter circuitry in handling k bit data; and energy consumed by the power amplifier to send k bit packet through a distance d . The transmitter and receiver energies in Equation (1) can therefore be expressed as (Kay et al., 2005):

$$E_{tx}(k, d) = E_{tc}.k + e_{amp}.k.d^n \quad (2)$$

$$E_{rx}(k) = E_{rc}.k \quad (3)$$

where, e_{amp} is the energy dissipated per bit per unit distance by the power amplifier; E_{tc} and E_{rc} represent energy dissipated per bit by the transmitter and receiver circuitry, respectively. The value of n depends on the propagation mode employed.

2.2.1 Propagation Models

Intra-cluster transmissions between cluster members and the CHs occur at relatively short distances; hence it is fair to assume a direct line of sight communication and a free-space propagation (*FP*) model; where n in Equation (2) is set equal to 2. Transmissions between the CHs and BS are relatively long distance transmission; thus a multipath transmission (*MP*) model is assumed and n is set equal to 4. Therefore, Equation (2) becomes:

$$E_{tx}(k, d) = \begin{cases} E_{tx}(k, d) = E_{tc} \cdot k + e_{fs} \cdot k \cdot d^2 & \text{for } FP \\ E_{tx}(k, d) = E_{tc} \cdot k + e_{mp} \cdot k \cdot d^4 & \text{for } MP \end{cases} \quad (4)$$

where, e_{mp} and e_{fs} are the amplifier parameters at free-space and multipath propagation modes respectively. Typical values of e_{mp} and e_{fs} as used in Heinzelman, et al. (2002) and Zouhair, Sadouq, & Mohamed (2014) are $0.0013 \text{ pJ/bit/m}^4$ and 10 pJ/bit/m^2 respectively.

2.3 Proposed Protocol

For the purpose of this study, a sensed area of $(X \times Y) \text{ m}^2$ with N nodes is deployed. The network is composed of a *BS* located outside the sensed area. It is assumed that the sensor nodes are operating on a fixed energy budget, but the *BS* has unlimited energy and can handle all data captured within the network as well as play the main coordinating role in the network. Each sensor in the network can be uniquely located by its x and y coordinates. In the model design and analyses, the sensor nodes may be deployed randomly or uniformly.

2.3.1 Cluster Grouping

The cluster sizes are determined at the beginning of the simulation. Based on the defined cluster size, the monitored space is divided by the cluster size to obtain the number of clusters. In this manner, all sensors that fall within a cluster space are grouped to form members of the cluster. In Figure 2, XY is the monitored area and C_{ij} are the cluster spaces such that i, j are x, y coordinates that respectively defining the cluster location on the cluster grid. In this manner, all sensor nodes (n_{ij}) whose i and j values are such that: $i \leq i_1$ and $j \leq j_1$ belong to cluster C_{11} . Similarly, members of C_{22} are defined as all sensor nodes whose i and j values are such that: $i_1 < i \leq i_2$ and $j_1 < j \leq j_2$.

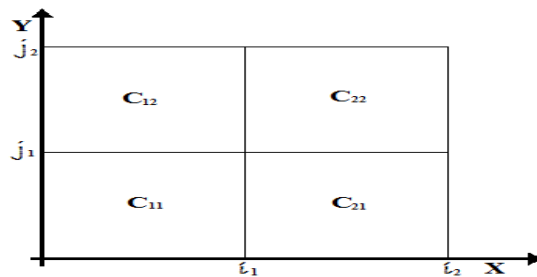


Figure 2. Cluster Grouping

2.3.2 Cluster Head Election

This study employs a predictive approach to CH election. The algorithm is designed to first estimate the cost. The node with the smallest cost estimate is favoured to become the CH. It should be pointed out here that the choice of a CH based on predicted energy expenditure alone may be catastrophic, as cluster members with lower residual energy may be elected as CHs leading to a shorter time before first node death (FND). It therefore becomes imperative to consider the residual energies of nodes in the choice of a CH.

A cost function (f) that weighs both the energy cost (E_{BS}) of transmitting collated data to the BS and residual energy of a node (E_{RS}) before electing a CH was developed. The cost function (f_{ch}) for electing the CH can therefore be formulated as:

$$f_{ch} = \gamma_1 E_{BS} + \gamma_2 E_{SP} \quad (5)$$

In Equation (5), E_{SP} is the energy spent by the node; which is obtained by subtracting the residual energy from the initial energy, γ_1 and γ_2 are constants to be optimised for the best results. E_{BS} can be calculated from Equation (2); assuming a multipath model for inter-cluster transmission;

$$E_{BS} = E_{tc} K_{tt} + e_{mp} k d_i^4 \quad (6)$$

where, K_{tt} and d_i are data collated within the cluster and distance of the node from the BS respectively. The d_i can be obtained by making use

$$d_i = \sqrt{(y_{bs} - y_n)^2 + (x_{bs} - x_n)^2} \quad (7)$$

Equation (5) is evaluated for each node in the cluster and the node with the least cost function becomes the CH for that round of data communication in the network.

2.3.3 Assisting Cluster Head (ACH) Election

The ACH is introduced to cushion the load burden on the CH. The work of the ACH is to collate data within the cluster and hop it to the CH for transmission to the BS. Since all the cluster members will be transmitting to the ACH, it must be chosen such that it satisfies the following criteria; it places the least energy burden (energy depletion) on the cluster; and nodes with higher energy residual are more favoured to play the role of ACH.

In order to satisfy the stated criteria, we must foremost estimate the energy burden imposed on a cluster (E_{ttch}) in a communication round if a particular node in the cluster is to be selected as the ACH. A cluster is imagined as a set (M) of n identical members, hence $M = \{m_i\}$, $i = 1, 2, \dots, n$. For every node (m_i), there is an associated distance (d_i) to the ACH. Since the cluster members are relatively close to each other, it is reasonable to assume a free-space propagation model. As such, if a cluster member m_i is selected as the ACH, the energy spent by the rest of the cluster members in transmitting to m_i (E_{ach}) is a simple sum which can be expressed as;

$$\begin{aligned} E_{ach} &= (E_{tc} k_1 + e_{fs} k_1 d_1^2) + (E_{tc} k_2 + e_{fs} k_2 d_2^2) + \dots + (E_{tc} k_{n-2} + e_{fs} k_{n-2} d_{n-2}^2) \\ &= (E_{tc} k_1 + E_{tc} k_2 + \dots E_{tc} k_{n-2}) + (e_{fs} k_1 d_1^2 + e_{fs} k_2 d_2^2 + \dots e_{fs} k_{n-2} d_{n-2}^2) \\ &= E_{tc} (k_1 + k_2 + \dots k_{n-2}) + e_{fs} (k_1 d_1^2 + k_2 d_2^2 + \dots k_{n-2} d_{n-2}^2) \end{aligned} \quad (8)$$

We can recast Equation (8) in a compact form as;

$$E_{ach} = ((E_{tc} \sum_{i=1}^{n-2} k_i) + (e_{fs} \sum_{i=1}^{n-2} k_i d_i^2)) \quad (9)$$

If all the nodes transmit the same size of data per round

$$k_i = k, \text{ for all } i = 1, 2, \dots, (n - 2)$$

$$E_{ach} = (E_{tc} k(n - 2) + (e_{fs} k \sum_{i=1}^{n-2} d_i^2))$$

$$E_{ach} = k \left((n - 2) E_{tc} + e_{fs} \sum_{i=1}^{n-2} d_i^2 \right) \quad (10)$$

At the end of a round of data collation, if all the data transmitted by the member nodes is successfully received by the ACH, the amount of data collated by the ACH can be expressed as;

$$K_{tt} = \sum_{i=1}^{n-2} k_i = (n - 2)k \quad (11)$$

This must be transmitted to the CH at an energy cost E_{ch} similarly expressed as;

$$E_{ch} = (E_{tc} K_{tt} + e_{fs} K_{tt} d_{ch}^2) \quad (12)$$

where, d_{ch} is the distance between the CH and ACH. Combining Equations (10) and (12) (i.e. the cost of collating data in the cluster and handing over to the CH), we obtained a fair estimate of the total energy burden imposed on the cluster (E_{ACH}) by the choice of any node say, m_i as the ACH;

$$E_{ACH} = k \left((n - 2) E_{tc} + e_{fs} \sum_{i=1}^{n-2} d_i^2 \right) + (E_{tc} K_{tt} + e_{fs} K_{tt} d_{ch}^2) \quad (13)$$

As defined in Equation (5), the cost function for the choice of an ACH can now be written as

$$f_{ach} = \gamma_3 E_{ACH} + \gamma_4 E_{SP} \quad (14)$$

where, E_{SP} is defined on per node bases. It is a measure of the residual energy in the node been considered for this role.

3.0 SIMULATIONS AND TESTBED DEPLOYMENT

3.1 Operation Of Char Scheme

The Cluster Head Assisted Routing (CHAR) scheme is divided into rounds. Each round as depicted in Figure 3 begins with a setup phase during which the nodes are grouped according to their location coordinates in the monitored space. CHs are selected by the BS as depicted in Figure 4 and ACHs are similarly selected. Intra cluster transmission begins with ACH receiving and aggregating data within the cluster, this phase ends with the CH transmitting

to the BS. The CH retains its role to the next round if its residual energy is above a set threshold of 0.8 times the average residual energy of the cluster.

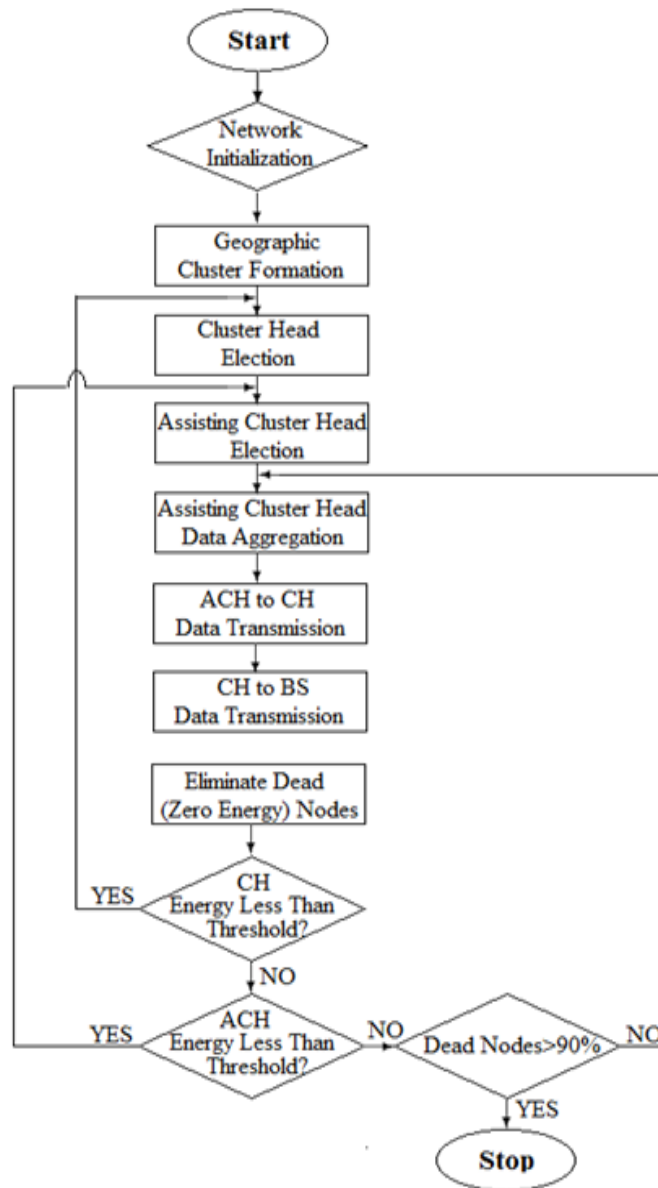


Figure 3. Operational Steps of CHAR Scheme

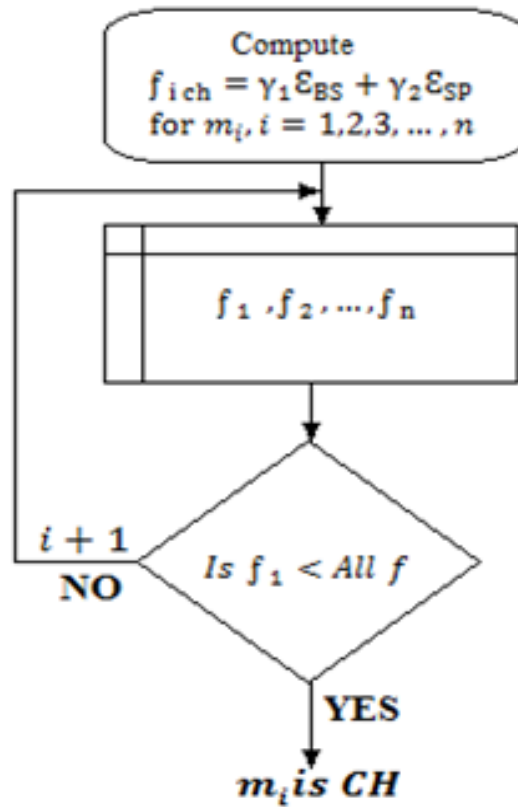


Figure 4. Cluster Head Election Steps

3.2 Simulations

The proposed algorithm was implemented in two environments. The first set of simulations was carried out in a Matlab environment; while the second set of simulations was carried out in a quasi-real environment using an improvised Test-Bed (Adetona, Ahemba, & Imoize, 2018) in order to validate its performance in Matlab. To allow for comparative analyses of the CHAR algorithm and an existing routing protocol, LEACH (Heinzelman, et al., 2002) was used. To examine the individual impact of its features on the energy profile of a network, simulations were done in an ordered manner as follows: Implement LEACH, modify LEACH by introducing the ACH, modify LEACH with the new cost function and implement CHAR scheme.

3.2.1 Simulations in Matlab Environment

Simulations in Matlab were done using 100 sensor nodes uniformly distributed in a 100 m^2 space. The multipath radio model and other radio network parameters were adopted from Zouhair, et al., (2014); and presented in Table 1.

Table 1. Model Parameters

Parameters	Values
Network Size	100 m ²
Number of Sensor Nodes	100
Initial Energy	0.5J
Packet Size	200bits
Receiver Electronics	50n J/ bit
Transmitter Electronics	50n J /bit
Amplifier Parameter for Free-Space	100p J/bit/m ²
Amplifier Parameter for Multipath	0.001p J j/bit/m ⁴
Crossover Distance	87 m

3.2.2 Validation of the proposed Algorithm

The algorithm was implemented in an improvised Test bed (Adetona et al., 2018) to further substantiate its performance in terms of power management in Matlab. The test bed is comprised of two node types, namely the normal nodes and the BS. For the normal nodes, an ESP8266-12 WIFI module is conditioned to simulate the action of a sensor node (see Figure 5). The ESP8266-12 is one of the series of high performing integrated wireless system on chip designed for space and power constrained mobile platforms and with an unsurpassed ability to function as a standalone application with minimal space requirements. Unlike regular wireless sensor nodes, ESP 8266 WIFI module does not have an inbuilt power supply unit or battery hence a 9 V external battery is condition by a voltage regulating circuit to power the test node and as well as voltage measuring circuit for monitoring the power consumption in the nodes and an operating algorithm. The BS comprised of a personal computer running a program (WSN validator) that simulates the behavior of the BS (see Figure 6).

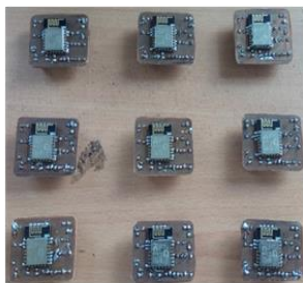


Figure 5. Sample of Sensor nodes
(Adetona et al., 2018)

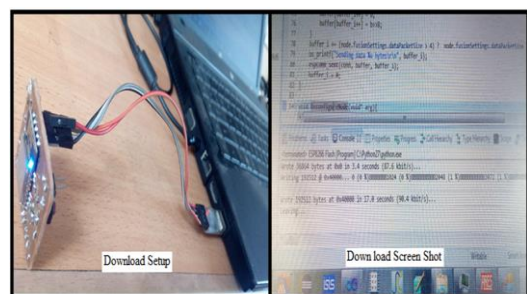
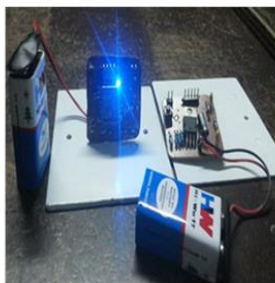


Figure 6. Downloading the
Firmware into the Sensor Nodes
(Adetona et al., 2018)

In order to validate the proposed protocol experimentally, the WSN algorithms developed in Heinzelman, et al., (2002) and our proposed CHAR scheme were compiled and downloaded into the chip for testing as shown in Figure 6.

4.0 DISCUSSION

For the purpose of comparison and analyses, the CHAR scheme which combines the role of an ACH and a derived decision making, cost function was implemented alongside LEACH, LEACH with ACH and LEACH with the cost function. Table 2 presents First Node Death (FND) and Last Node Death (LND) counts for all simulations; whereas Figure 7 depicts a combined plot of active nodes versus number of rounds for all implementations. It can be seen from the combined plot that, the FND in simulations of LEACH and LEACH modified by the cost function occurred at 4250 and 4447 rounds respectively; while the FND in LEACH modified with the ACH and the CHAR simulations respectively occurred at the 4795 and 4798 rounds representing a 12.8% and 12.9% increase in the number FND count over LEACH.

In terms of LND which was compared at 10% active node count. It is evident from Figure 7 that, LEACH and LEACH modified by the cost function performed similarly with no significant difference in the number of rounds, both LND counts occurring at 6612 and 6609 rounds. In fact modifying LEACH with the cost function alone resulted in an insignificant reduction in the number of rounds. This can be viewed as the additional cost of computing the cost function without a corresponding benefit in terms of energy conservation. On the other hand, introducing the ACH to LEACH improved the LND count by 188 rounds. When the ACH role is introduced to the cost function simultaneously (CHAR), an even greater improvement in the number of rounds was observed. The LND count increased by 389 over LEACH-C representing a 6% increase in the LND count.

Table 2. FND and LND Counts for all Simulations

Routing Scheme	FND Count	Impact		LND Count	Impact	
		Inc	% Inc		Inc	% Inc
LEACH	4250	Ref	Ref	6611	Ref	Ref
LEACH + f	4247	-3	-0.07	6610	-1	0.02
LEACH+ACH	4795	545	12.8	6799	188	3.00
CHAR	4798	548	12.9	7000	389	6.00

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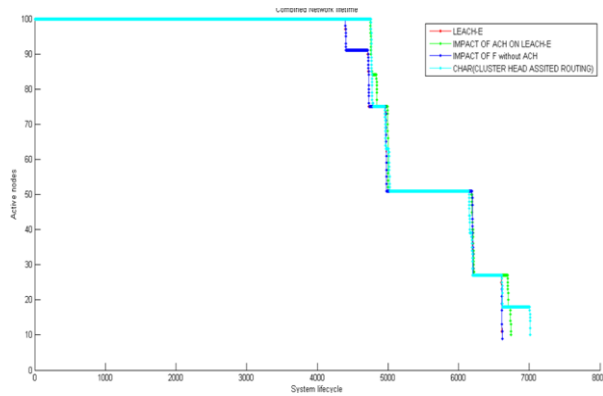


Figure 7. A Combined plot of Active Nodes versus Number of rounds for all implementations

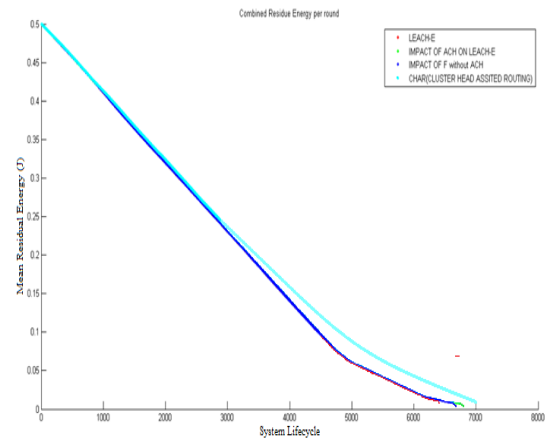


Figure 8. Combined Plot of Mean Residual Energy versus Number of Rounds for all implementations

When the ACH role is introduced to the cost function simultaneously (CHAR), an even greater improvement in the number of rounds was observed. The LND count increased by 389 over LEACH-C representing a 6% increase in the LND count.

To allow for a visual and comparative overview of the energy consumption profile of the proposed algorithm, Figure 8 presents a combined plot of mean residual energy versus number of rounds for all implementations. It is observed that there was no significant difference in the system's residual energy for all the schemes until the 2500th round. Beyond this, CHAR begins to distinguish as a better energy conserving algorithm. The mean residual energy plot for CHAR begins to appreciate against the other schemes until it attains a steady difference of about 0.023J. It is noted that CHAR scheme was the only simulation that got to the 7000th round.

Figures 9 through 12 depict the residual energy density (RED) of various schemes at the end of the simulation; whereas, Table 3 shows RED at the end of the simulation. This is a measure of how much energy was left unused/unutilized at the end of the simulation. The performance of the pair LEACH, LEACH+f and CHAR, LEACH+ACH were fairly similar. Comparing CHAR and LEACH, it can be seen from the Table 3 that, at the end of the simulation, 11, 5, 2, and 82 nodes in LEACH implementation had 0.1 J, 0.07 J 0.09 J and 0.01 J remaining respectively. This presents a total loss of 2.45 J whereas for CHAR, it can be seen from the table that 5, 2, and 93 nodes had 0.06 J, 0.05 J and 0.01 J respectively; representing a total energy residue of 1.33 J.

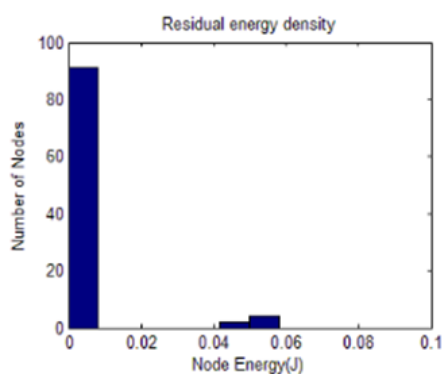


Figure 9. RED for CHAR Scheme

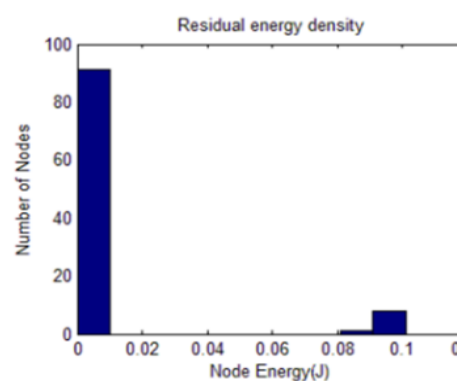


Figure 10. RED for LEACH + ACH

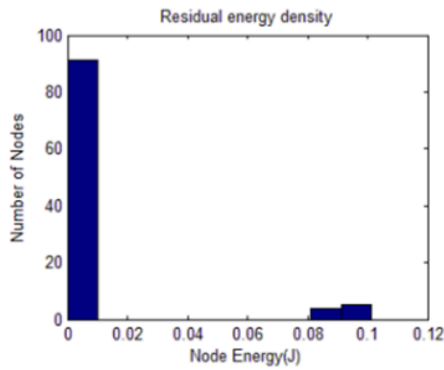


Figure 11. RED for LEACH + f

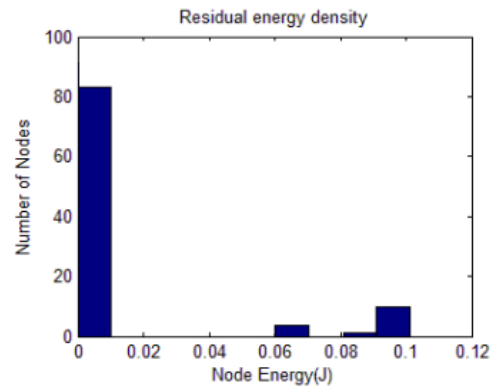


Figure 12. RED for LEACH

Table 3. RED at the end of simulation

<i>Routing Scheme</i>	<i>Residual Energy per Node(j) (Maximum value per bar)</i>	<i>Number of Nodes per bar</i>	<i>Residual Estimate (J)</i>
LEACH	0.1	11	1.1
	0.07	5	0.35
	0.09	2	0.18
	0.01	82	0.82
Total			2.45
LEACH+ACH	0.1	7	0.7
	0.09	6	0.54
	0.01	87	0.87
Total			2.11
LEACH+f	0.1	11	1.1
	0.09	2	0.18
	0.01	87	0.87
Total			2.15
CHAR	0.06	5	0.3
	0.05	2	0.1
	0.01	93	0.93
Total			1.33

The results obtained from the ESP8266ES Wi-Fi based test bed are presented in Figures 13 and 14. The rate of battery depletion when normal LEACH protocol, (Adetona, Ahemba, & Imoize, 2018) where a head is selected based only on highest residual energy, was running is presented in Figure 13; while the rate of battery depletion when our proposed CHAR algorithm, where a head is selected based on two parameters: highest residual energy and cost of transmission to the base station, was running is presented in Figure 14.

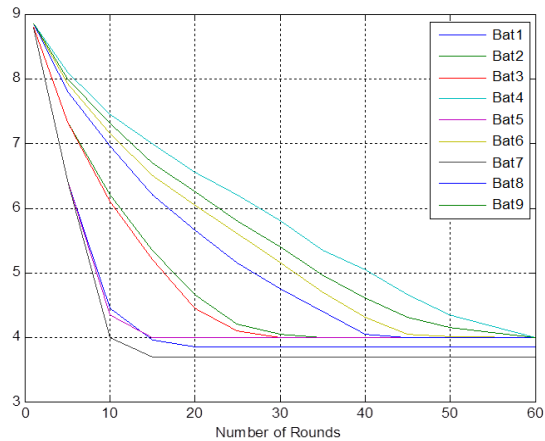


Figure 13. Battery Voltage Versus System life (Rounds) for LEACH

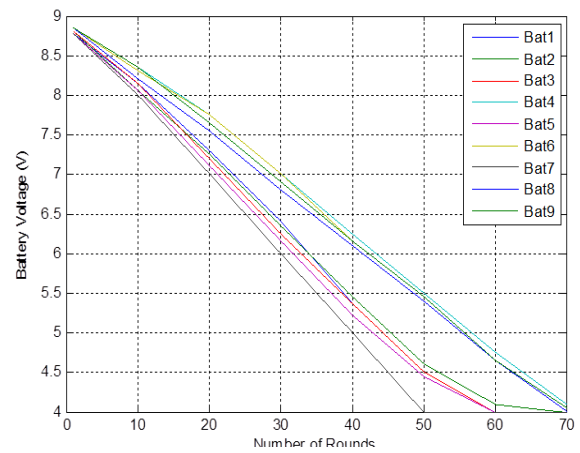


Figure 14. Battery Voltage Versus System life (Rounds) for CHAR

For the purpose of evaluating the numerical value of the performance of the CHAR and LEACH routing protocols in terms of energy conservation, Figure 15 presents the mean values of battery voltage for all batteries against system life for the two routing protocols. Figure 15 reveals that the rate at which battery depleted in normal LEACH and CHAR routing protocols are 50% and 10% respectively. This indicates that batteries depleted faster in normal LEACH than CHAR routing protocols. Consequently, there is an improvement in energy conservation in the CHAR scheme over normal LEACH protocol. It can also be observed that CHAR produced a more even and gradual battery depletion rate leading to a longer network life of 20 rounds more than normal LEACH.

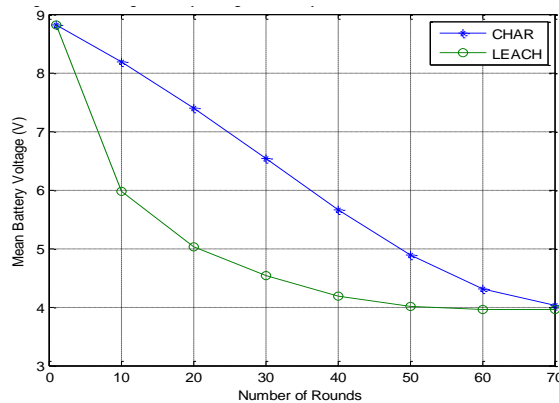


Figure 15. Average Battery voltages versus system life for LEACH and CHAR

5.0 CONCLUSIONS

In this study, a CHAR scheme has been designed and a comparative analysis carried out. The objective of this algorithm is to overcome the inherent problem of over-burdened CHs in a hierarchical/clustered network structure; hence ACHs are proposed. The role of the proposed ACH is to share the high energy burden on the CH by receiving and aggregating data within the cluster, while the CH is left with the role of transmitting aggregated data to the BS. A predictive CH and ACH selection technique based on a derived cost function is utilized. The cost function for CH election is a weighted combination of the residual energy of a node, and

the energy cost of transmitting to the BS. The node with the least cost is favored to be elected as the CH.

Simulation results show that an improved energy consumption profile of a WSN characterized by a superior FND count, a more gentle energy depletion curve and better energy utilization can be achieved by fine-tuning the CH choice process and reducing the burden of the CHs. For an even better performance, future study works may focus on performance evaluation to define the optimum values of the weighting parameters in equations (5) and (14) for improved decision making.

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